Emissions Research Activities

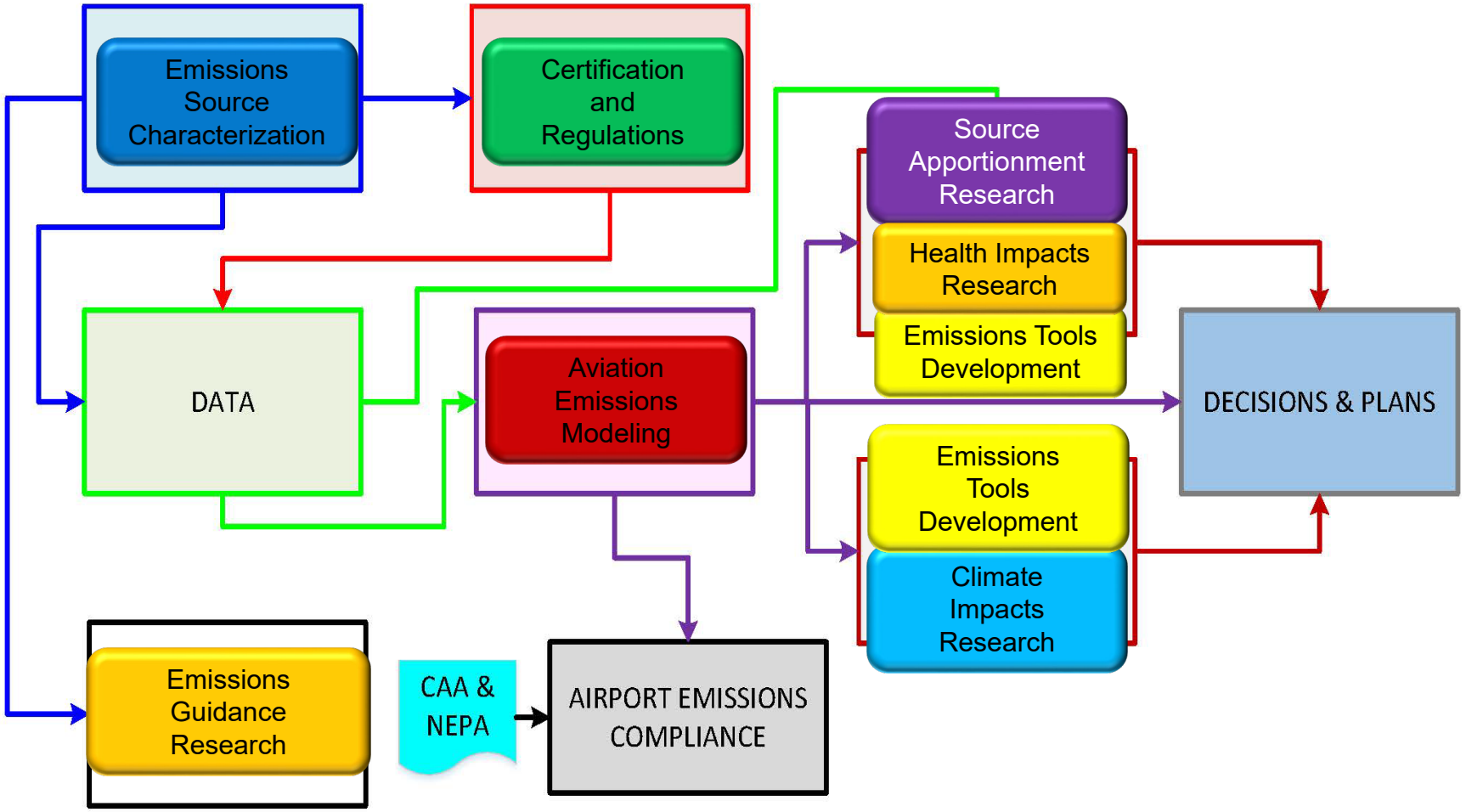
Presented To: REDAC E&E Subcommittee

By: S. Daniel Jacob & Ralph Iovinelli

Date: 15 September 2021

Federal Aviation Administration

Emissions Research Roadmap



EMISSIONS RESEACH ROADMAP ELEMENTS – CURRENT AND FUTURE

EMISSIONS MEASUREMENT	Emissions Characterization, Corrections Development, Fuel Composition Effects, Emissions from Advanced Technology, Rig Tests, Engine Tests, Collaboration with CLEEN, NASA, Industry and International Partners
VOLATILE PM MODELING	New methodology to model volatile particulate matter in the vicinity of airports
NVPM MASS CALIBRATION	Maturing the charged particle mass analyzer (CPMA) methodology for in-line and in situ calibration of nvPM mass instruments
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IMPACTS OF HIGH ALTITUDE EMISSIONS	Impacts of various sources of emissions in the upper atmosphere including supersonic transport, high altitude long endurance UAVs, rocket emissions
SUPERSONICS	Technology, Forecasts and Emissions in collaboration with Noise/ CLEEN Divisions
CONTRAIL PHYSICS & MITIGATION	Improved understanding of contrail formation and real-time predictability of the radiative forcing of contrails as affected by technology, fuels and operations. Mitigation of Contrails through technology, fuels and operations (Avoidance)
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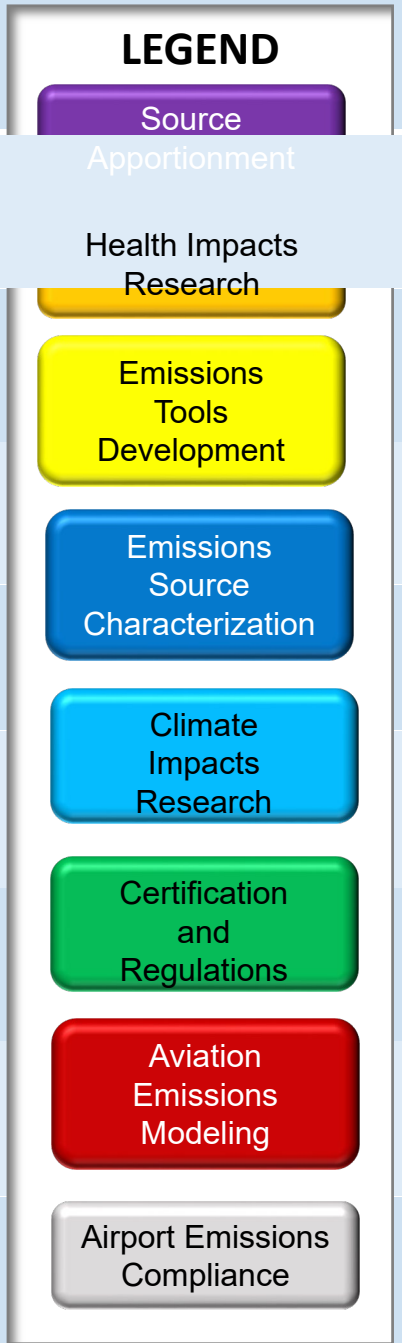
AAM LIFE CYCLE EMISSIONS	Lifecycle benefits/disbenefits of transporting people and goods via AAM



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LEGEND

- Source Apportionment
- Health Impacts Research
- Emissions Tools Development
- Emissions Source Characterization
- Climate Impacts Research
- Certification and Regulations
- Aviation Emissions Modeling
- Airport Emissions Compliance

Emissions Measurements

- **Lack of Standard Day (i.e. Ambient Conditions) Corrections for nvPM Emissions (CAEP)**
- **The role of Naphthalenes on nvPM Emissions (CAEP, Tools)**
- **Inform Cruise nvPM and NOx Emissions Modeling (CAEP, Tools)**
- **Collaboration: CLEEN Projects on nvPM Prediction Models (Tools)**
- **Collaboration: Emissions from Advanced Technology (NASA ASCR and Altitude Test – Technology, Tools, CAEP)**
  - Advanced Rich Quench Lean
  - Lean Burn

Emissions Measurements

Started: October 2019

April 2021 | October 2021 | April 2022 | October 2022

ASCENT 02: HONEYWELL RIG TEST

Jet A with 29 P3 T3 Test Points

Deliverables: Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation

Success Criteria: Methodology applicable to all technologies
Inclusion in ICAO Annex 16 Vol.II

Reference Fuel 1

Deliverables: nvPM Emissions for Fuel 1 and Cruise nvPM Methodology Validation

Success Criteria: Usable data for emissions prediction for different fuel composition

Reference Fuel 2

Deliverables: nvPM Emissions for Fuel 2 and Cruise nvPM Methodology Validation

Success Criteria: Usable data for emissions prediction for different fuel composition

Reference Fuel 3

Deliverables: nvPM Emissions for Fuel 3 and Cruise nvPM Methodology Validation

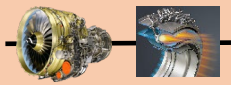
Success Criteria: Usable data for emissions prediction for different fuel composition

T | T+1 | T+2

FUTURE MEASUREMENTS

Collaboration with NASA
- ASCR + Fuels
- Altitude Tests

CLEEN Collaboration



ENGINE/ RIG TEST DATA & ANALYSIS

DELIVERABLES: EMISSIONS PREDICTION MODELS FOR ADVANCED TECHNOLOGY

CLEEN ASCENT Projects on Emissions Prediction Models

Success Criteria: Methodology usable in AEDT for Emissions Prediction for Advanced Technology Engines

Collaborators: EPA, Transport Canada

Federal Aviation Administration

Emissions Measurements

Deliverables:

- Ambient Conditions Corrections Methodology and Cruise nvPM Methodology Validation
- nvPM Emissions for Different Fuel Specifications

Success Criteria:

- Methodology applicable to all technologies for inclusion in ICAO Annex 16 Vol. II
- A validated cruise nvPM Methodology
- Data for nvPM emissions prediction for different fuel compositions

Future Work:

- Additional work on Honeywell Rig Test not anticipated for ASCENT 02
- Research on Emissions Predictions for higher Overall Pressure Ratio engines needed

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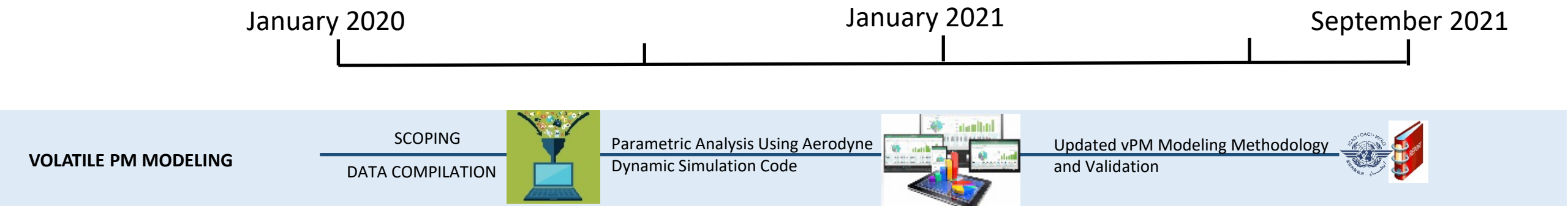
Microphysical Modeling of Volatile Particulate Matter (vPM) – CAEP, Tools

- The non-volatile modeling methodology that is part of the First Order Approximation 4.0 was updated during the CAEP/11 cycle. The vPM modeling methodology of FOA4 is based on a single dataset. More datasets are available now that can be used to develop more representative vPM emissions estimates from aircraft engines in the vicinity of airports



Available Datasets: APEX I, II and III, AAFEX I and II, ND-MAX/ ECLIF2 and future EU AVIATOR

Status: Methodology is proposed for inclusion in to ICAO Doc 9889 – Airport Air Quality Manual. Will also be implemented in AEDT.

Source Apportionment/ Health Impacts

Emissions Tools Development

Aviation Emissions Modeling

Microphysical Modeling of Volatile Particulate Matter (vPM)

Deliverables:

- Update to First Order Approximation 4 (FOA4) Volatile Particulate Matter Modeling Methodology that can be included in ICAO Doc 9889 and implemented in AEDT and final reports documenting the methodology
- Contrail microphysics modeling and validation

Success Criteria:

- Demonstrated improvement over the current vPM prediction methodology
- Enhanced understanding of contrail microphysics in the near field.

Future Work:

- Methodology may need refinement as newer measurement datasets become available

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Transitioning a research nvPM Mass Calibration Methodology to Certification (ASCENT 69 – builds on ASCENT 02 results) - Certification

- Due to the lack of a standardized non-volatile Particulate Matter (nvPM) source, current nvPM mass calibration methods lead to much larger measurement uncertainties than the measurement uncertainties of gaseous instruments used in certification. The use of a Charged Particle Mass Analyzer (CPMA) has been shown to reduce uncertainties in calibration and measurement of nvPM mass in research setting. The objective of this task is to mature and transition this methodology for use in engine certification.

Started JANUARY 2021

APRIL 2021 — APRIL 2022 — DECEMBER 2022

NVPM MASS CALIBRATION

INSTRUMENT ACQUISITION
LABORATORY TESTS

ENGINE & START CART
TESTS AT AEDC

ANALYSIS

SAE ARP
A16 V2 UPDATE

Emissions Source Characterization

Certification and Regulations

Collaborators: EPA, USAF AEDC, Transport Canada

Transitioning a research nvPM Mass Calibration Methodology to Certification

Deliverables:

- Charged Particle Mass Analyzer (CPMA) based calibration methodology ready for inclusion in Annex 16 Vol.II and ARP 6320 and Final Reports

Success Criterion:

- CPMA in-line calibration for nvPM mass during certification and eliminate the need for filter based calibration methods

Future Work:

- None anticipated

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Dispersion Model Development (A19) and Monitoring Study (A18) Research

- **Challenge: Address artificial model exceedances of 1-hour NO_2 National Ambient Air Quality Standard**
  - Delays National Environmental Policy Act (NEPA) review of Federal actions at airports
- **Research Solutions:**
  - Compare performance of regulatory models to real-world monitor values (@ LAX, ORD, etc.)
  - Collaborate with EPA to improve AERMOD dispersion analyses for aviation-specific emission sources
  - Develop a validated aviation-specific emissions dispersion model
- **Expected Outcomes – A more accurate aircraft-specific model to demonstrate airport air quality compliance that is acceptable to EPA.**
  - Improved aircraft source characterization and plume rise in EPA's AERMOD for aircraft emissions
  - A new model reflecting the best science and algorithms
  - Short and long-term monitoring around airports for modeled-monitoring comparison study and model validation
  - Better characterization of AQ impacts on communities surrounding airports through modeling and monitoring study

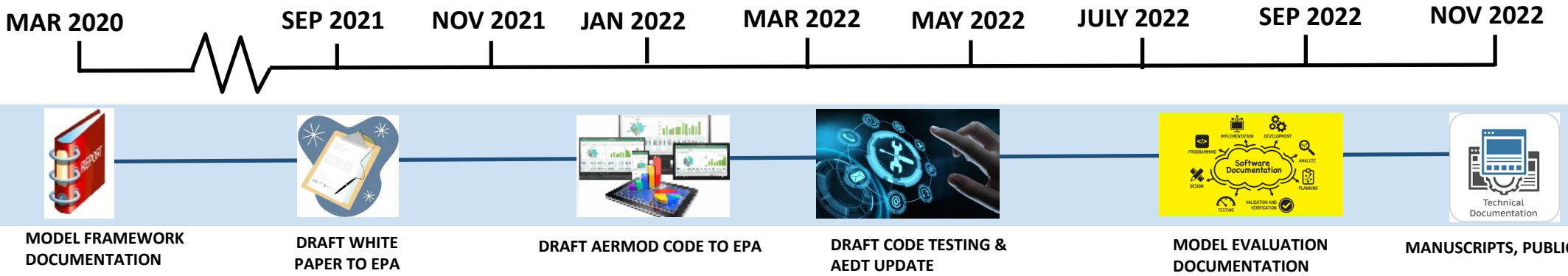
Performance of Regulatory Models: Comparison to LAX measurements

- Both dispersion models (AERMOD and LASPORT) simulate lower NOx concentrations than the monitored concentrations at four core monitors at LAX.
- For NOx, aircraft NOx emissions are **not** a dominant contributor to the total measured concentrations at four core monitor stations.
- Both models have simulated SO_2 dispersion
  - Aircraft SO_2 is a good tracer for model evaluation
  - Diagnostics to understand modeled over-predictions late in the evenings and early mornings of SO_2 is in progress

Development of Aviation-Specific Dispersion Model (ADM) and AERMOD Update: FAA-EPA Joint Task Group

- Primary focus of AERMOD updates are to incorporate plume rise and improved source characterization for aircraft emissions. Working closely with EPA.
- Regulatory update to the EPA's *Guideline on Air Quality Models* focused on science improvements to the aircraft emission modeling in AERMOD Modeling System - Appendix W Update.

Tentative timeline for needed deliverables to meet Appendix W update target date



Aviation Specific Dispersion Model Development

Deliverables:

- Improved AERMOD dispersion model with better source characterization
- Fully validated new aviation dispersion model that is ready for AEDT implementation, and incorporates improved physical and chemical processes

Success Criteria:

- Updated source characterization of aircraft emissions code
- Updated jet plume model that takes into account wakes + vortices
- Improved NO_2 chemistry in 1-hr NO_2 predictions and code that meets design document criteria

Future Work:

- Utilize airport monitoring campaigns data for model validation;
- An improved meteorological model and state-of-science algorithms; and
- Implementation of a better performing model in AEDT for regulatory compliance demonstration.

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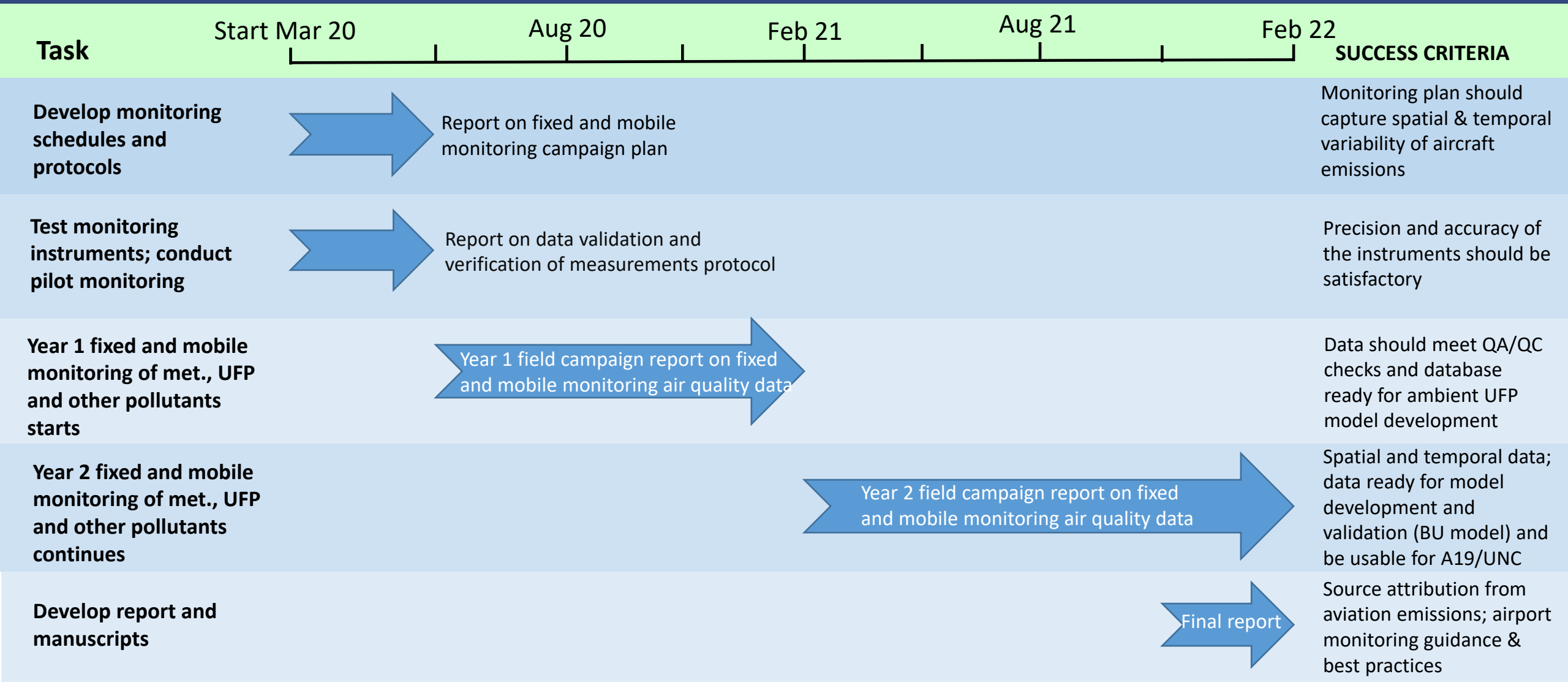
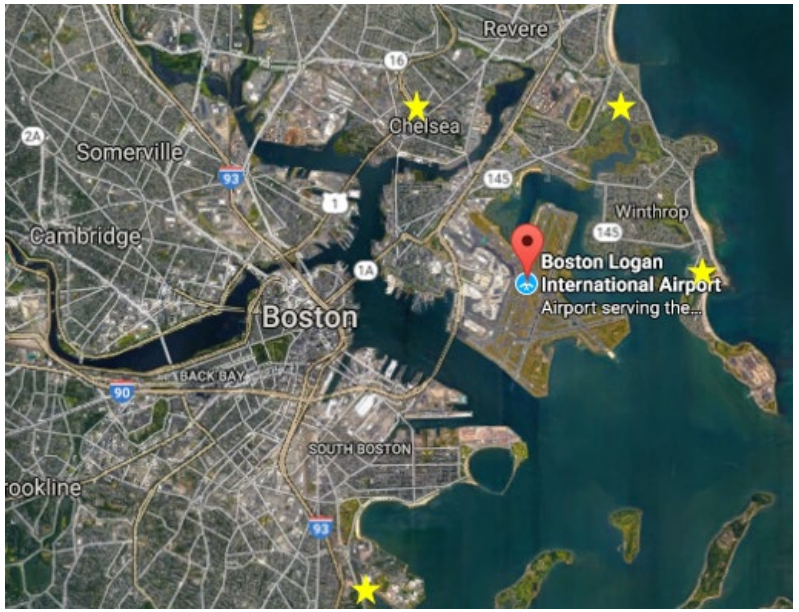
Airport Monitoring



A18: Airport Monitoring: Stationary Platform

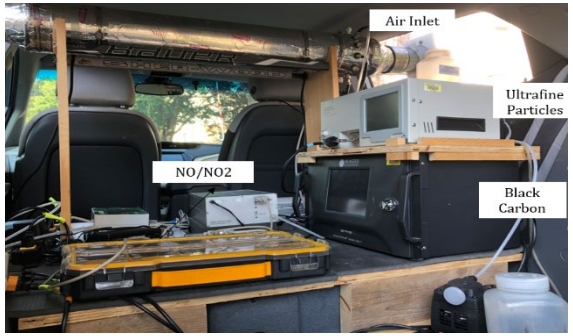
Current Study (Arrivals and Departures)

- Expanded field campaign to address unanswered questions related to aviation source attribution
  - Additional pollutants, additional sites, consideration of departures as well as arrivals
- Develop insights about spatiotemporal patterns of the aviation-attributable portion of multiple air pollutants, determining implications for potential studies of health effects
- Compare monitoring-based source attribution estimates with those derived from dispersion modeling (ASCENT 19)



Particle Number
TSI CPC 3787
(1 sec)

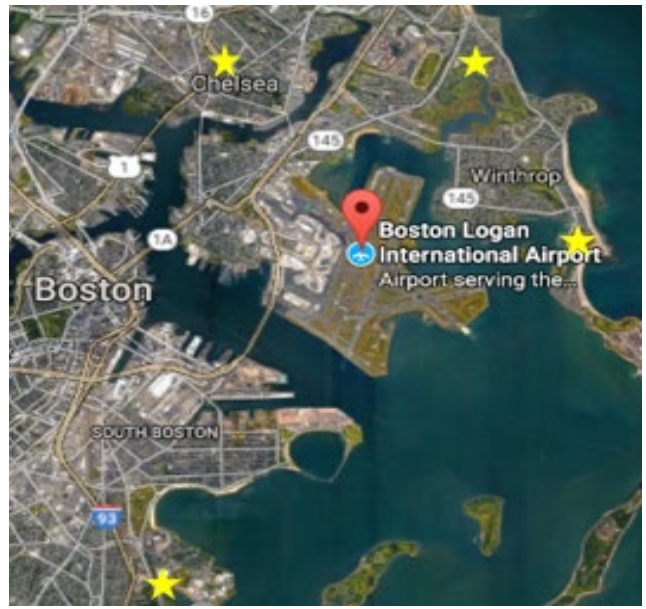
Particle Size Distribution
TSI FMPS 3091
(1 sec)



A18: Airport Monitoring: Status

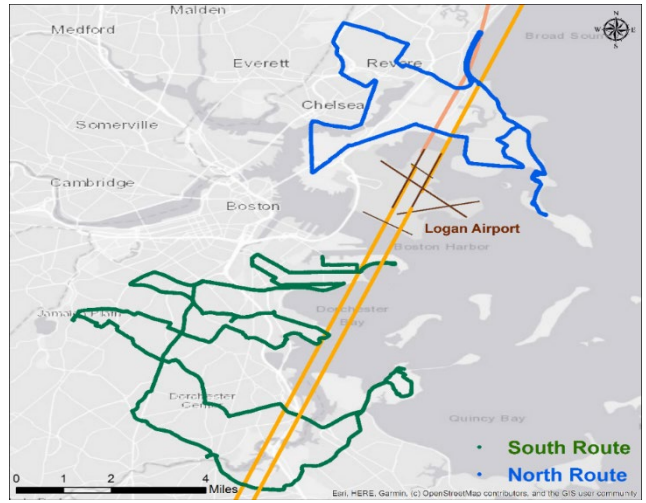
Stationary Sites

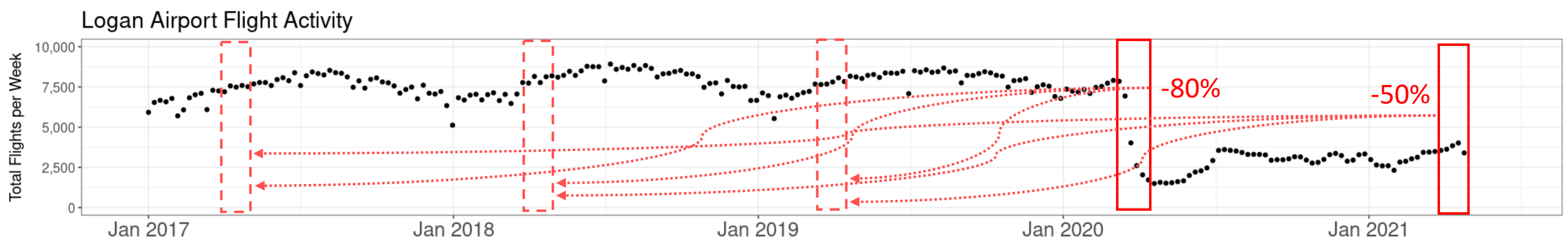
1. Monitors setup Chelsea (April 2020), Revere (July 2020), Winthrop (August 2020), and UMASS (Feb 2021)
2. **~60 million records of 1-second PNC data at each site**
3. ~ only 4% of data removed during QAQC
4. Minute and hourly aggregated data for analysis



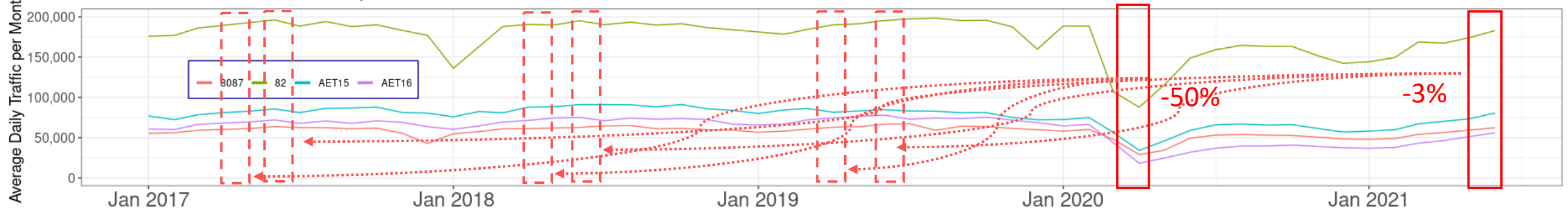
Mobile Monitoring

1. North and South Routes developed spring and launched summer monitoring 2020
2. Since August 2020 we have collected **over 550 hours of air pollution data on 140 days** (North Route = 78 days; South Route = 63 days) including every season and month while covering a wide variation in time of day (i.e. daytime, nighttime, and overnight), weekday/weekends; and holidays (i.e. New Years day, July 4th).

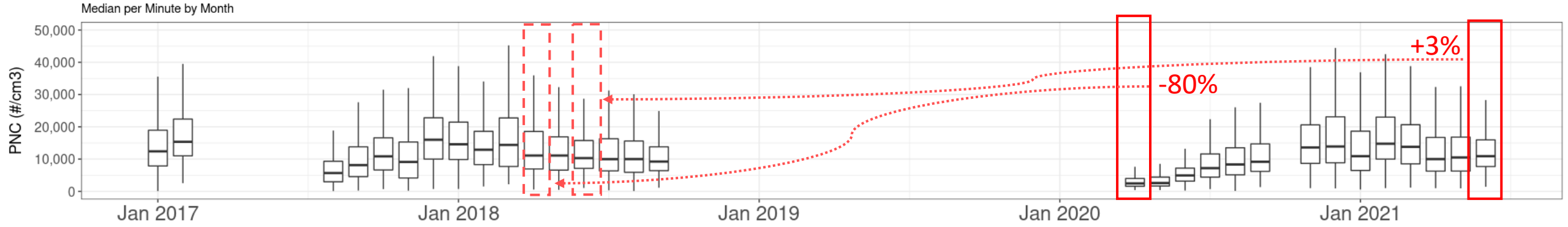




B. Automobile Traffic in Boston, MA



C. Particle Number Concentration in Chelsea, MA



Airport Monitoring

Deliverables:

- Demonstration of measurement concepts for long-term spatial and temporal UFP, BC and NOx around BOS that can be extended to other airports
- Data for statistical and mathematical model development and validation purpose
- Data sharing protocol and platform with other ASCENT and non- ASCENT projects

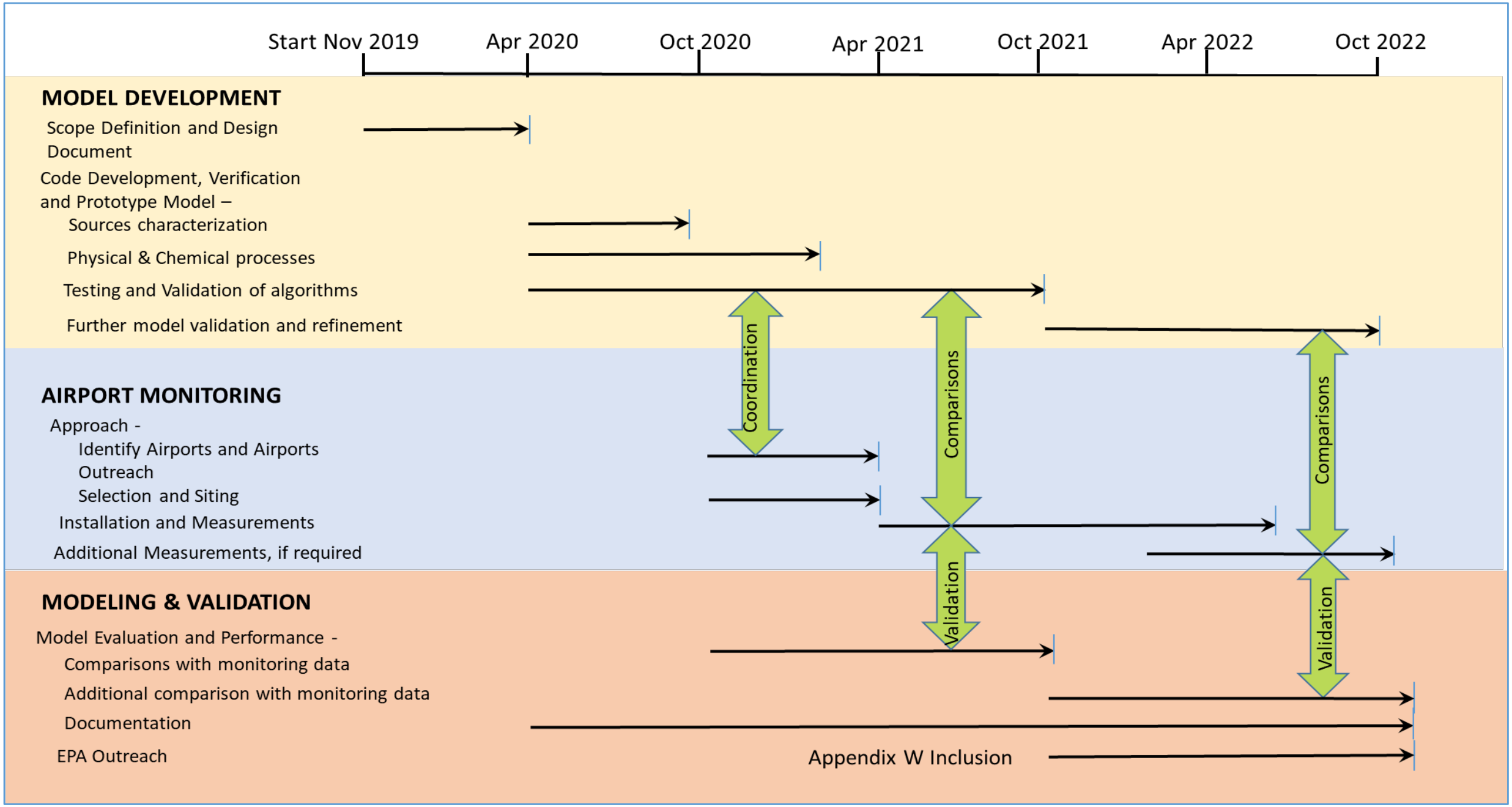
Success Criteria:

- Spatial and temporal data; data ready for model development and validation and for use by A19
- Source attribution from aviation emissions
- Airport monitoring guidance & best practices

Future Work:

- Additional airport monitoring campaigns for model validation (A19/UNC);
- Development of ambient UFP prediction model around airports;
- UFP and Health impact studies - Epidemiological model and field campaign; and
- Joint Emission and Noise study design and health studies

A19 & A18 Action Plan: Aviation-Specific Dispersion Model Development & Airport Monitoring Plan



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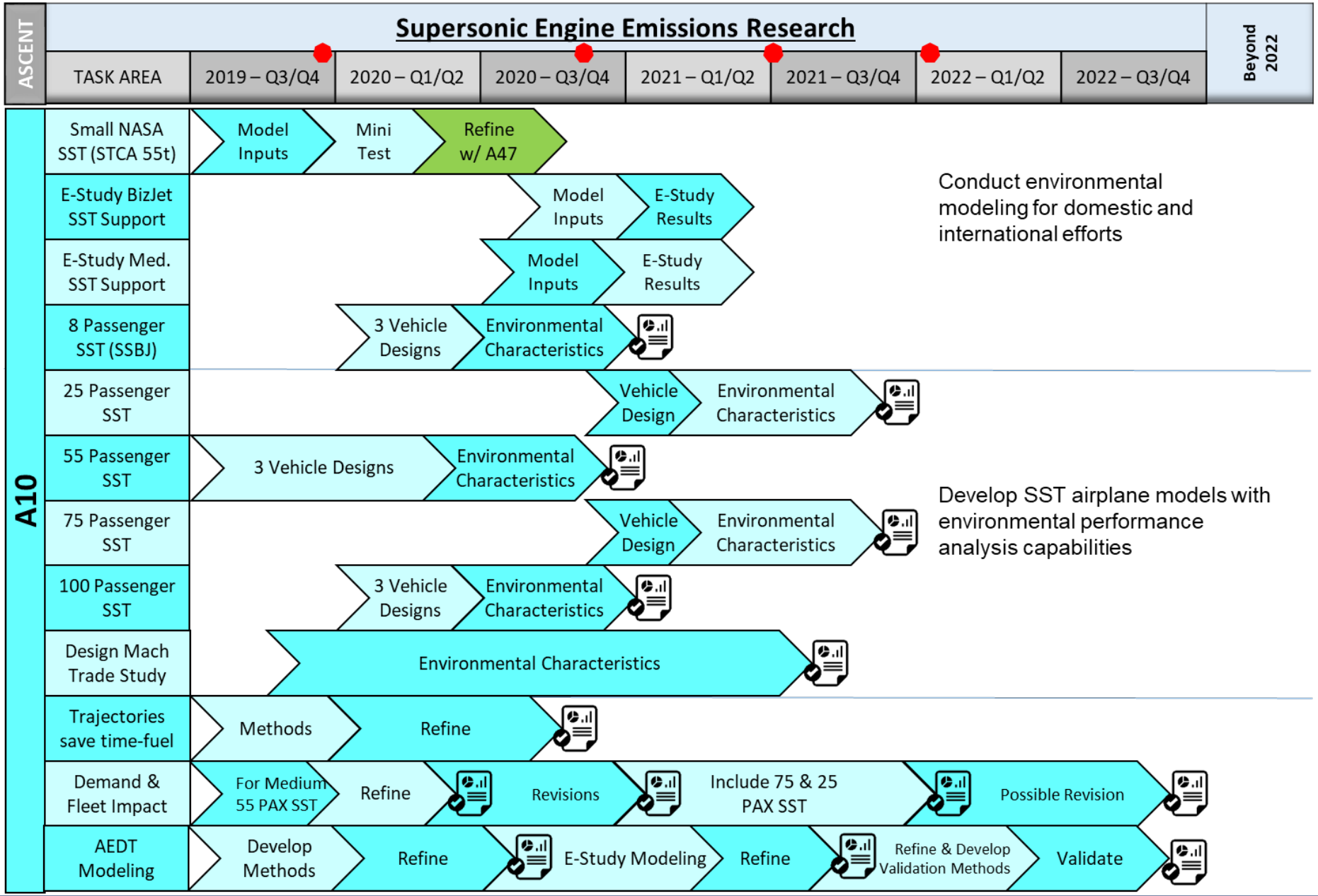
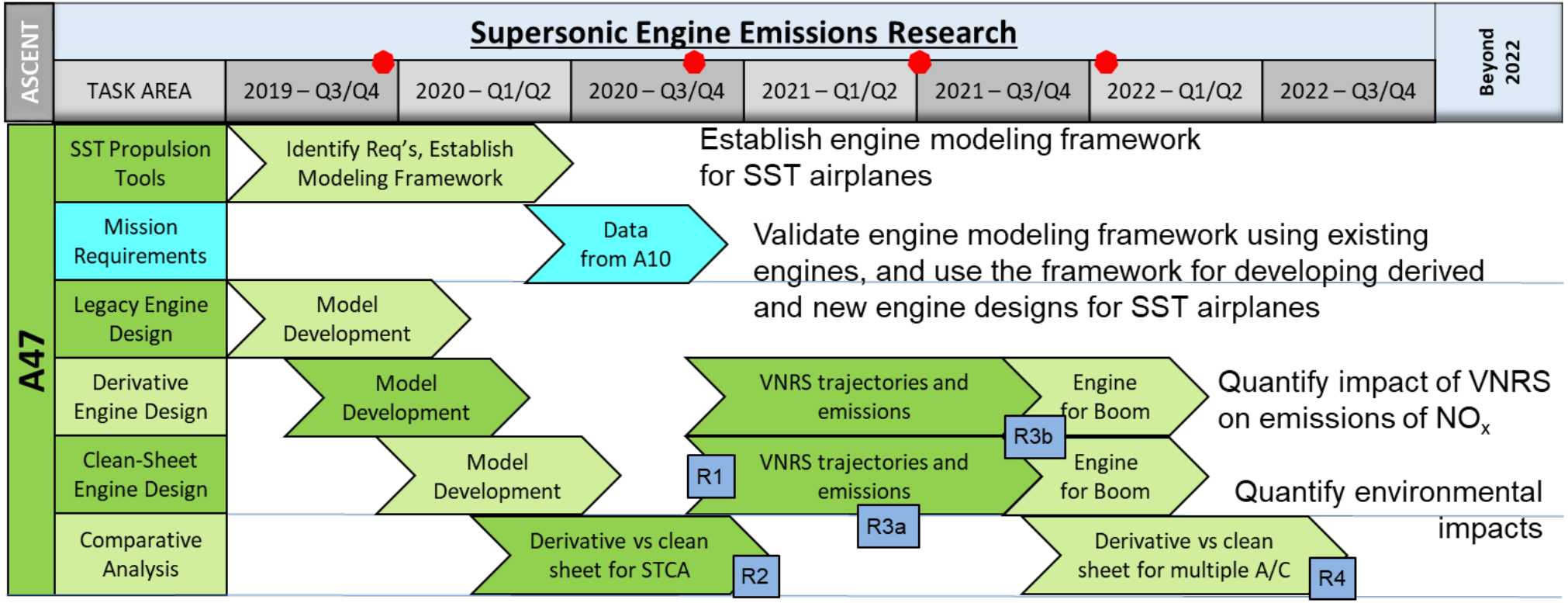
Supersonic Engine Emissions Research – Policy, CAEP, Tools, Impacts

- With the proposed supersonic aircraft, development of:
  1. Airplane models with environmental performance capabilities; and;
  2. Demand routes to estimate potential impacts are needed.
- Environmental modeling is needed for domestic and international efforts. ASCENT 10 addresses these needs not only for emissions but also for noise.
- Proposed engine designs for the new SST use existing cores. ASCENT 47 investigates the emissions benefits that may be realized if a clean sheet engine design is adopted from a modeling perspective.



Develop SST airplane demand & routes to estimate potential impacts

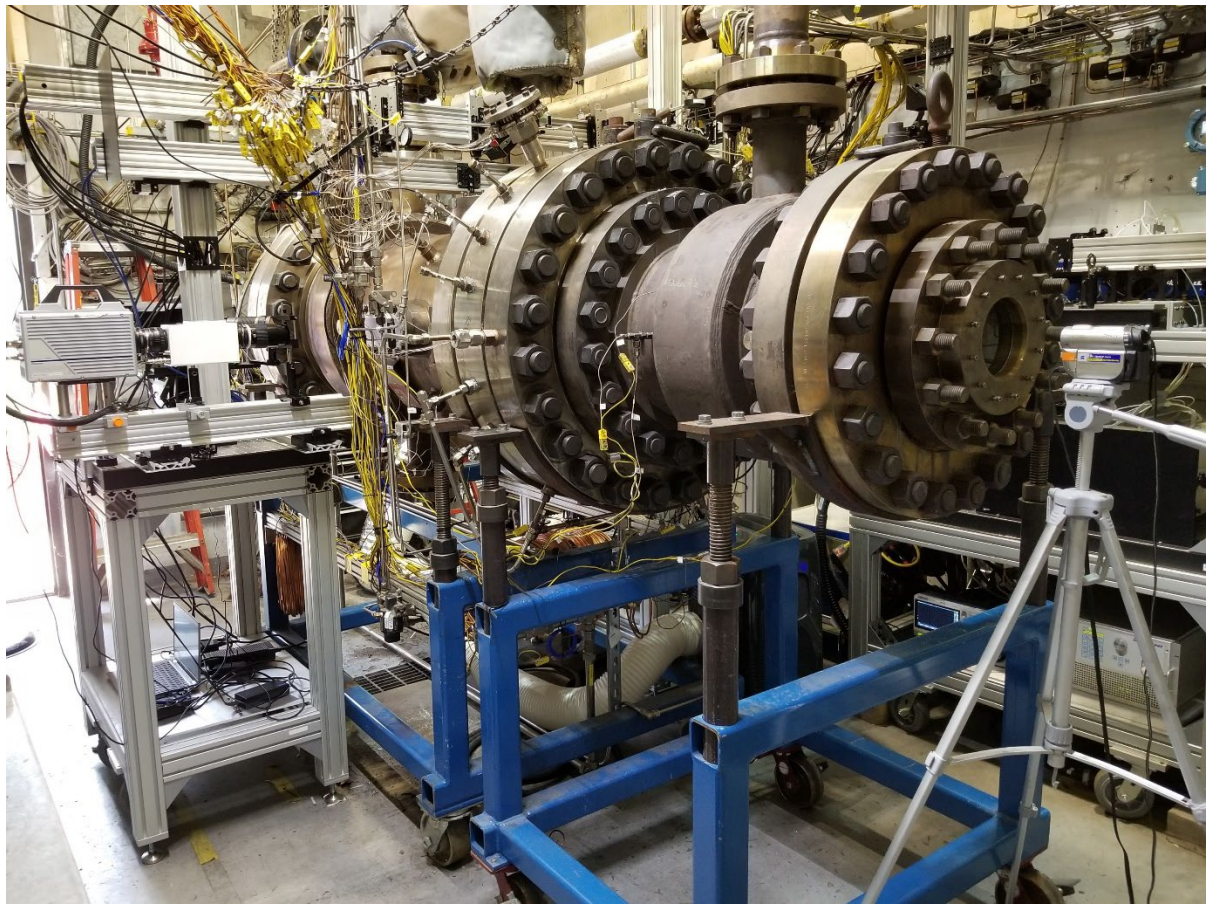


Reports

- R1: Information Paper to WG3/5: "Investigation of the effects of VNRS on LTO emissions of engines for supersonic transport aircraft"
- R2: Paper submitted to AIAA SciTech: "The impact of design space constraints on the noise and emissions from derivative engines for civil supersonic aircraft"
- R3: Working Paper to WG3/6 (R3a), revised for WG3/7 (R3b): "Accounting for climb out emissions in the supersonic LTO emissions cycle"
- R4: Journal paper evaluating clean sheet and derivative engine performance and emissions for aircraft with a range of design Mach numbers

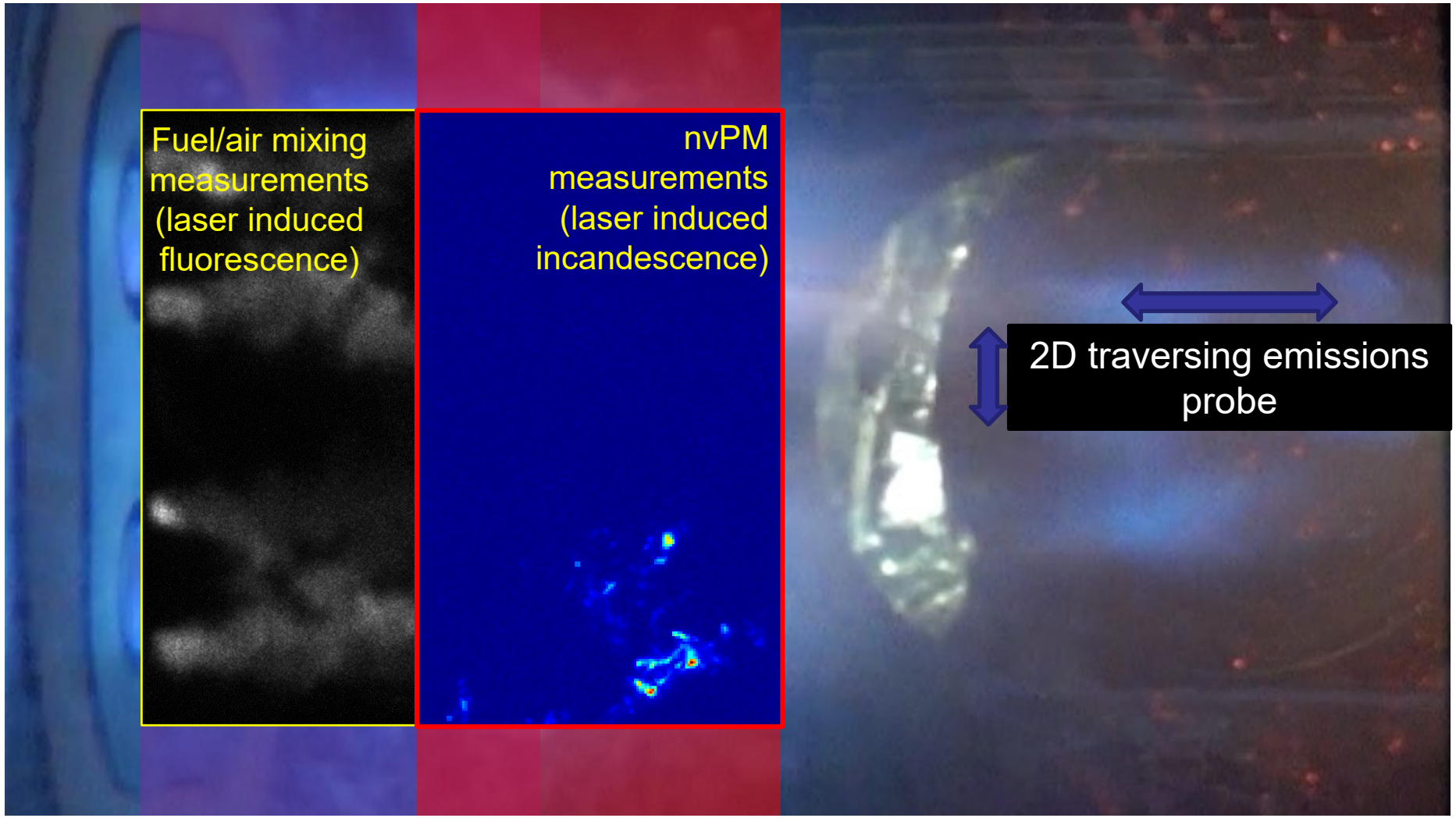
A74: Low Emission Premixed Combustion Technology for Supersonic Civil Transport

- Collaboration between Georgia Tech and General Electric
- Objectives/Outcomes:
  - Measure/understand operability and emissions of novel combustor for supersonic transport
  - Develop and validate design tools for this type of combustor
- Methods:
  - High-pressure & temperature combustor facility at GE
  - State-of-the-art laser diagnostics from Georgia Tech deployed at GE
  - Industrial (affordable) and academic (high-fidelity) large eddy simulations



Test cell at GE Research (Niskayuna NY) with laser diagnostics from Georgia Tech. Three Georgia Tech students were on-site at GE from June-August.

A74: Example Experimental Data



Video of combustor operating at $p_3 \approx 150$ psia, $T_3 \approx 800$ F

Supersonic Engine Emissions Research

Deliverables:

- ASCENT 10: SST Modeling Tools and Demand Scenarios
- ASCENT 47: Emissions Impacts of clean sheet supersonic engine design
- ASCENT 74: Emissions performance of a novel lean pre-mixed combustor for a SST engine

Success Criteria:

- Realistic aircraft and engine designs to estimate environmental impacts
- Forecast fleet comparing well with actual future fleet

Future Work:

- Inform future SST engine emissions standards
- Emissions predictions methodologies for full flight gaseous and particle emissions

EMISSIONS RESEACH ROADMAP ELEMENTS – CURRENT AND FUTURE

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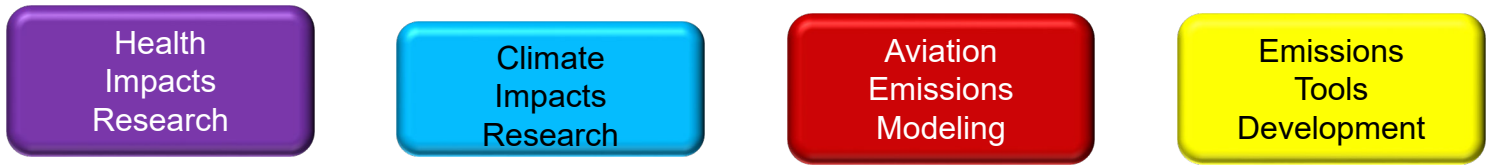
AVIATION CO_2 TRENDS	Examine CO_2 Emissions Trajectories for Domestic Aviation
AAM LIFE CYCLE EMISSIONS	Lifecycle benefits/disbenefits of transporting people and goods via AAM

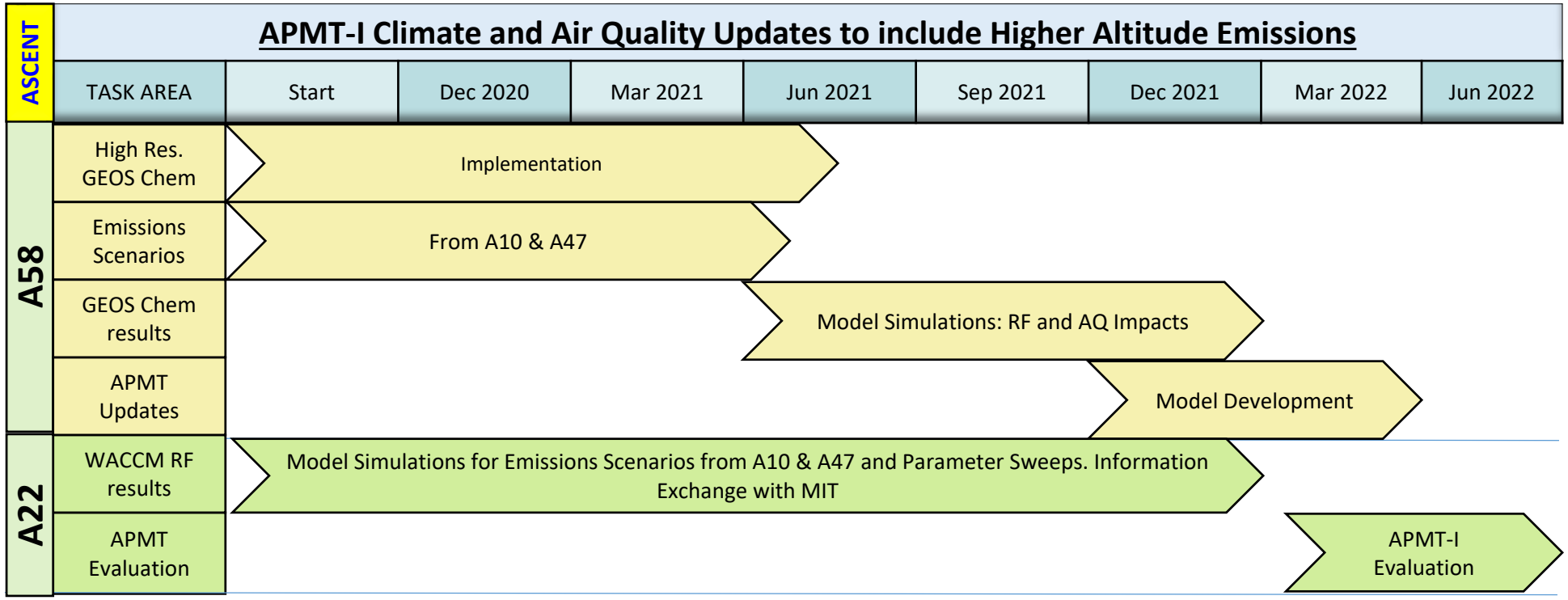
LEGEND

- Source Apportionment
- Health Impacts Research
- Emissions Tools Development
- Emissions Source Characterization
- Climate Impacts Research
- Certification and Regulations
- Aviation Emissions Modeling
- Airport Emissions Compliance

Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations – Tools, Policy, CAEP

- Commercial supersonic aircraft and high-altitude and long-endurance (HALE) unmanned aerial vehicles offer the potential to become enablers for new use cases and business models in the aviation sector.
- Combustion emissions of these vehicles will have atmospheric impacts which differ from conventional subsonic aviation due to the higher operational altitudes. Emissions at higher altitudes are associated with a different chemical environment, longer emission lifetimes, and greater distances over which the emissions will be transported.
- The APMT-Impacts Climate and Air Quality tools need to be updated to capture the impact of such high altitude emissions.





Collaborators: NASA

Improving Policy Analysis Tools to Evaluate Higher-Altitude Aircraft Operations

Deliverables:

- ASCENT 22 & 58: Radiative Forcing and Climate Impacts for high altitude Emissions Scenarios for APMT Implementation
- ASCENT 58: Air Quality Impacts Tool for High Altitude Emissions
- ASCENT 58: Climate Impacts Tool for High Altitude Emissions
- ASCENT 22: Evaluation of APMT-I Climate and Air Quality Tools

Success Criterion:

- APMT-I Climate and Air Quality Tools that can be used in operational Costs Benefits Analyses to include high altitude emissions

Future Work:

- Tools update and evaluation based on latest scientific knowledge

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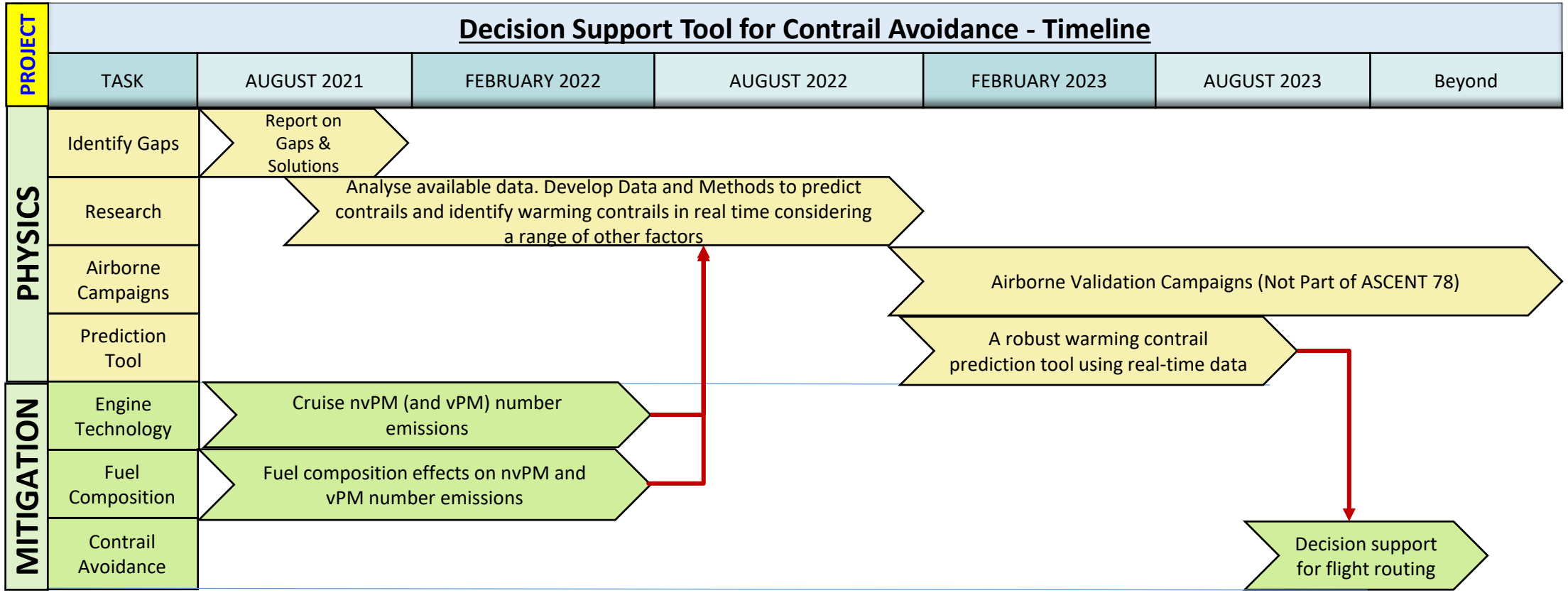
A78: Contrail Avoidance Decision Support and Evaluation (MIT – NEW)

- **Understanding:** Aircraft Exhaust Contrails (Aviation Induced Cloudiness – AIC) are the most important aviation transient effects that impact climate. Contrails and induced-cirrus clouds have global mean climate impact that is of the same order as CO_2.
- **Challenge:** The effects are highly variable in space and time. It is important to be able to predict if a contrail is a warming contrail or a cooling contrail.
- **Research:** Investigate science and data gaps, develop methods to predict contrails at various spatial and temporal scale. More importantly, develop the capability to identify formation of warming contrails in real-time, along with changes in fuel burn, that will also consider engine technologies and fuel composition. Use existing datasets (e.g., ND-MAX/ ECLIF)
- **Mitigation:** Develop approaches that mitigate formation of warming contrails, through technology, fuel composition and/or operations while accounting for tradeoffs in terms of fuel burn and overall climate impact of all aviation emissions.
- **Expected Outcome:** Identify approaches and decision support tools that could be used by industry to cost effectively mitigate the overall climate impacts of aviation via contrail mitigation.


Decision Support Tool for Contrail Avoidance - Timeline
PROJECT
TASK
AUGUST 2021
FEBRUARY 2022
AUGUST 2022
FEBRUARY 2023
AUGUST 2023
Beyond
PHYSICS
Identify Gaps
Report on Gaps & Solutions
Research
Analyse available data. Develop Data and Methods to predict contrails and identify warming contrails in real time considering a range of other factors
Airborne Campaigns
Airborne Validation Campaigns (Not Part of ASCENT 78)
Prediction Tool
A robust warming contrail prediction tool using real-time data
MITIGATION
Engine Technology
Cruise nvPM (and vPM) number emissions
Fuel Composition
Fuel composition effects on nvPM and vPM number emissions
Contrail Avoidance
Decision support for flight routing

Mitigation of AIC Climate Impacts

Deliverables:

- Identification of data and science gaps and development of approaches to address gaps to predict real-time contrail formation at flight by flight resolution and impacts of potential mitigation actions to identify effective mitigation solutions – Resulting Action: Research to Address Gaps
- Development of tools to predict warming contrails and changes in fuel use using operations, technology, and fuel composition to assess the practicability of avoiding warming contrail formation. Validate using existing and future airborne data
- Real time tool with appropriate data stream that can predict formation of warming contrails
- Evaluation of optimal flight routing to minimize climate impacts of aviation

Success Criteria:

- Real time predictability of warming contrails
- Decision support tools that could be used by airlines to inform flight routing. Needs to determine means of warming contrail avoidance, increased fuel burn, and other climate impacts in real time

Future Work:

- Implement an integrated research program that would identify approaches that could be used by industry to cost effectively mitigate the overall climate impact of aviation via contrail mitigation

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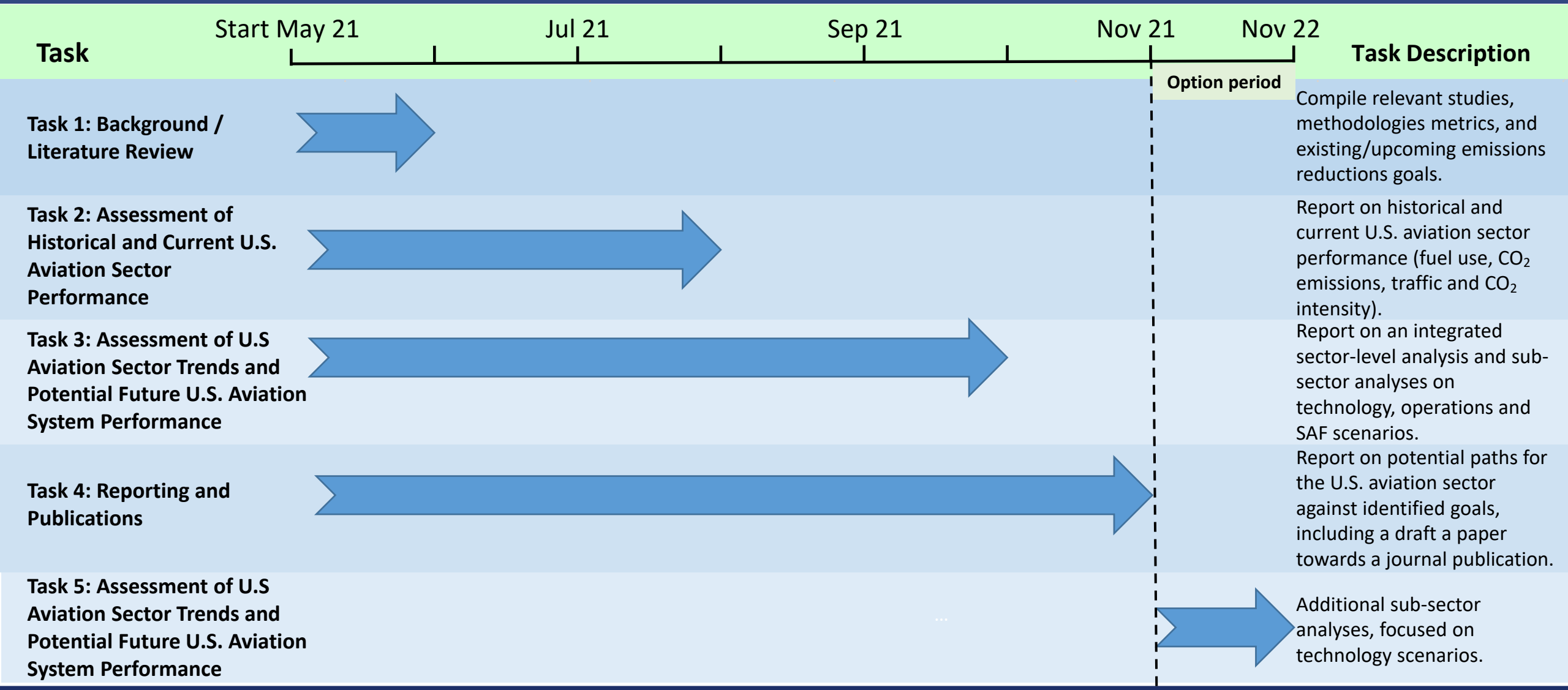
Aviation CO_2 Challenge – 10 Year Update



Aviation CO_2 Challenge – 10 Year Update

Deliverables:

- Report on potential paths for the U.S. aviation sector against identified goals
- Provide data to support policy-making processes

Success Criteria:

- Determine whether emissions reduction targets are achievable
- Assess and report on potential future U.S. aviation sector performance, including aircraft technologies scenarios, operations scenarios and SAF scenarios

Future Work:

- Not anticipated at this time

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Life Cycle Analysis of Advanced Air Mobility and Drone Emissions
(ASCENT NFO Pending)

Deliverables:

- Literature review of relevant existing studies, and details of upcoming AAM and drone designs;
- Life cycle analysis of AAM vehicle and drone emissions (that affect both air quality and climate change), evaluating any benefits from offsetting other transit modes; and,
- Scenarios for the deployment and operations of AAM vehicles and drones, including life cycle emissions analyses.

Success Criteria:

- Perform initial research on potential changes in lifecycle emissions that would result from the integration of AAM and drones (including both climate and air quality impacts) through various scenarios

Future Work:

- None anticipated at this time

Summary

- **Comprehensive Emissions Research Portfolio**
- **Research needs based on:**
  - Characterizing emissions of current and future engine technologies and fuels
  - Impacts reduction
  - Tools development
  - CAEP / domestic policy needs
- **Establishing internal and external collaborations**
- **Successful outreach through Annual AEC Roadmap Meeting**